20th AIAA Aerodynamic Decelerator Systems Technology Conference and Seminar

Reefing of Quarter Spherical Ribbon Parachutes used in the Ares I First Stage Deceleration Subsystem

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Agenda

- Introduction
- Ares I Parachutes
- Reefing Ratio Development
- Conclusion
- Acknowledgments

Objectives

- Introduce the Ares I First Stage parachutes
- Discuss reefing quarter spherical parachutes compared to literature
- Identify superior suspension line length drag area normalization curve

Ares I Program

- NASA Constellation Program
  - Ares I man-rated rocket
    - First stage is a reusable solid rocket booster (Space Shuttle variant)
    - Second stage is an expendable liquid rocket (Apollo variant)
  - Ares V unmanned, heavy-lift rocket
    - Uses 2 solid rocket boosters, similar to Ares I first stage
- Currently developing parachutes to recover the first stage of the Ares I Rocket
  - Similar to Space Shuttle Solid Rocket Booster (SRB) recovery system
  - Pilot parachute, drogue parachute with reefed stages, 3 main parachute cluster with reefed stages
- Baseline: quarter spherical ribbon parachutes

Ares I Parachutes - Pilot

Pilot Parachute Properties:

- Nominal diameter of 11.5 ft
- Geometric porosity of 19.5%
- Kevlar structural members, nylon ribbons
- Vent hoop construction

Currently Planned Ares I Flight Configuration:

- Permanently reefed to near full open for Ares I

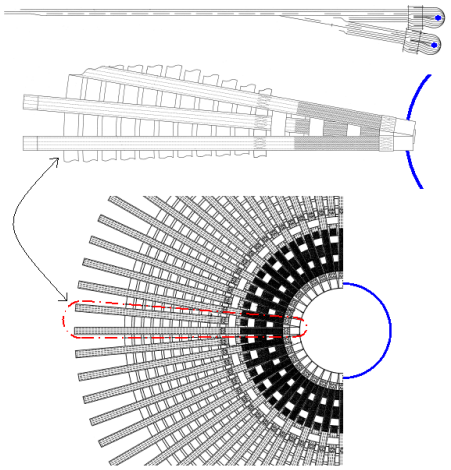
Successfully Completed Drop Tests:

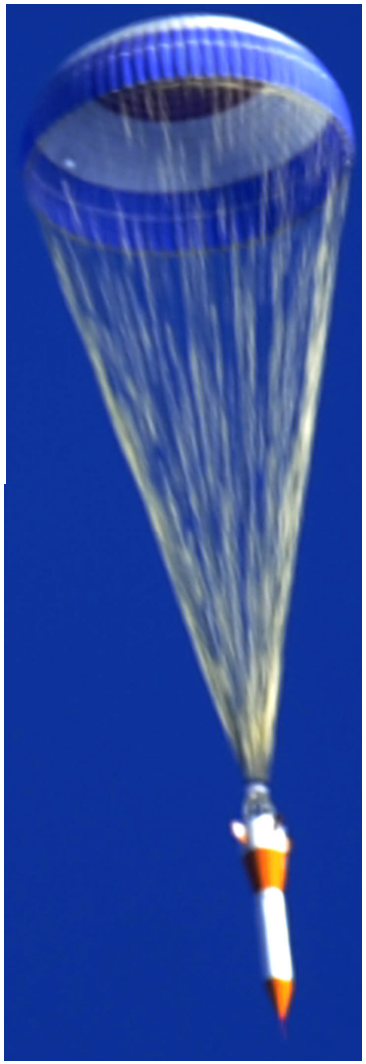
- Pilot Parachute Drop Test (PDT)-1
- PDT-2
- PDT-3R
- Drogue Parachute Drop Test (DDT)-1
- DDT-2 (two; separate programmer and pilot)

Ares I Parachutes - Drogue

Drogue Parachute Properties:

- Nominal diameter of 68 ft
- Geometric porosity of 19.5%
- Kevlar structural members, nylon ribbons
- Double vent hoop construction





Currently Planned Ares I Flight Configuration

- First stage reefed to near 40% drag area
- Second stage reefed to near 60% drag area
- Third stage reefed to near 80% drag area

Successfully Completed Drop Tests:

- DDT-1
- DDT-2, additional fullness added to vent region

Ares I Parachutes - Main

Main Parachute Properties:

- Nominal diameter of 150 ft
- Geometric porosity of 11.5%
- Kevlar structural members, nylon ribbons
- Double vent hoop construction

Currently Planned Ares I Flight Configuration:

- First stage reefed to near 20% drag area
- Second stage reefed to near 40% drag area

Successfully Completed Drop Tests:

- Main Parachute Drop Test (MDT) -1 (tub)
- MDT-2 (tub)
- DDT-1
- DDT-2, porosity changed to 15.0%

Ares I Parachute Drop Test Summary

Measured Reefed Drag Areas (not normalized to L_e/D)

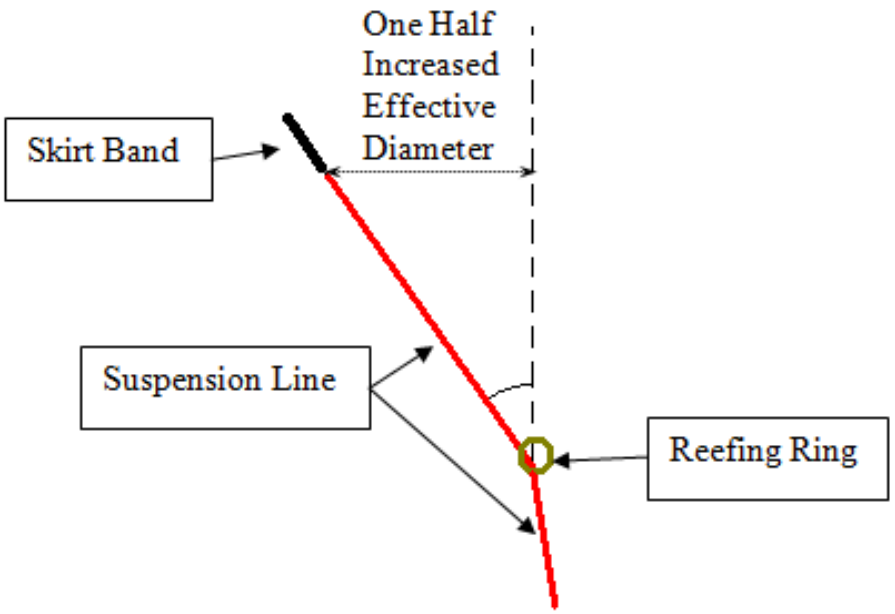
Drop Test	Reefing					
	Pilot	1st Stage Drogue	2nd Stage Drogue	3rd Stage Drogue	1st Stage Main	2nd Stage Main
Pilot Drop Test #1	76.6%	x	x	x	x	x
Pilot Drop Test #2	84.1%	x	x	x	x	x
Pilot Drop Test #3R	98.6%	x	x	x	x	x
Main Drop Test #1	x	x	x	x	19.7%	31.2%
Main Drop Test #2	x	x	x	x	25.1%	46.7%
Drogue Drop Test #1	100%	39.3%	59.4%	73.3%	19.8%	39.2%

Reefing Ribbon Parachutes

- Information on quarter spherical parachutes difficult to obtain
- Knacke published reefing line curves for flat circular and conical ribbon parachutes
- Required to normalize parachute data to compare to literature
  - Knacke published normalization curves for ribbon parachutes
- Initially, Space Shuttle Solid Rocket Booster (SRB) and Ares I First Stage Parachutes did not lie on this line
- Normalizations of every kind investigated
  - Primary normalization is to suspension line length
  - Wolf provided additional suspension line normalization curve

Effective Reefing Line Length

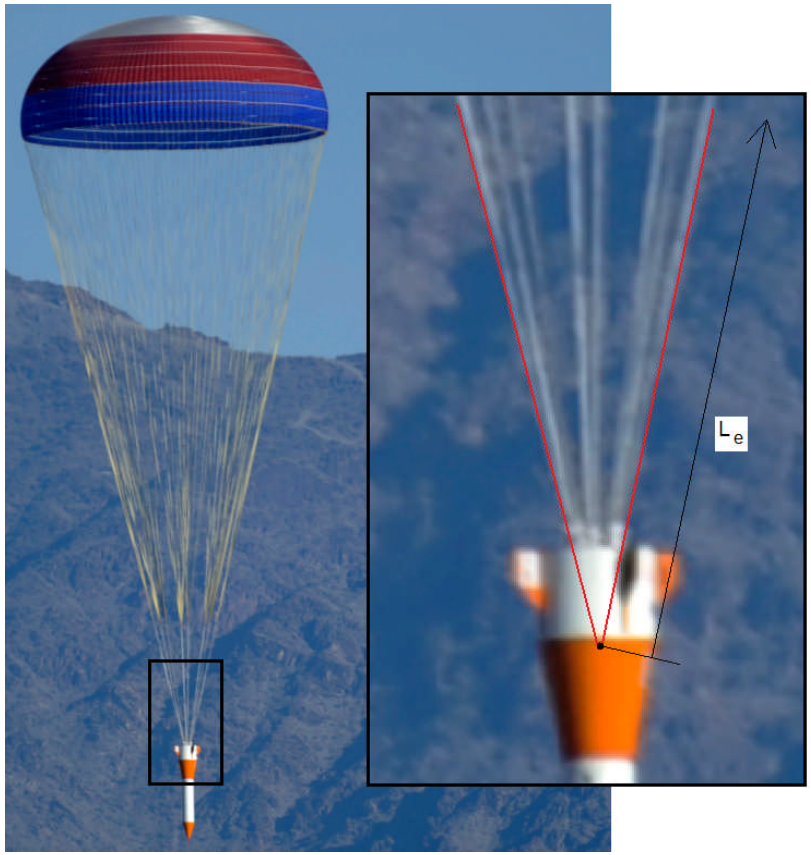
- This correction is specific to Ares I parachute design
- CANO is used to help predict suspension line angles



Nominal Diameter

- Nominal diameter used in
  - Reefing ratio definition
  - Suspension line length normalization
- In general, actual nominal diameter is not an important parameter to identify
- Larger effect possible in SRB parachutes when drag areas were investigated after years of flight.
  - Frequent washing and drying may shrink parachutes – full open drag area is reduced
  - New reefing lines each flight maintain reefed stage drag area

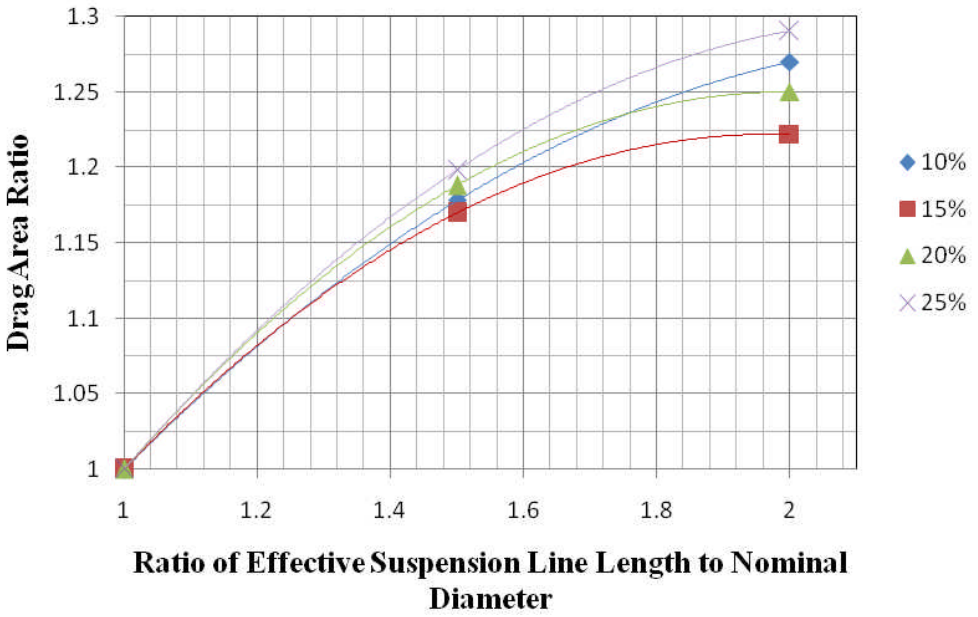
Effective Suspension Line Length



- The closer to parallel the suspension lines are, the lower the inboard force on the canopy skirt
- A reduction of inboard force at the canopy allows the parachute to inflate to a greater diameter
- Suspension lines may not converge to a point
- These suspension lines appear to the skirt of the canopy to be longer
- This effective length, Le, is obtained

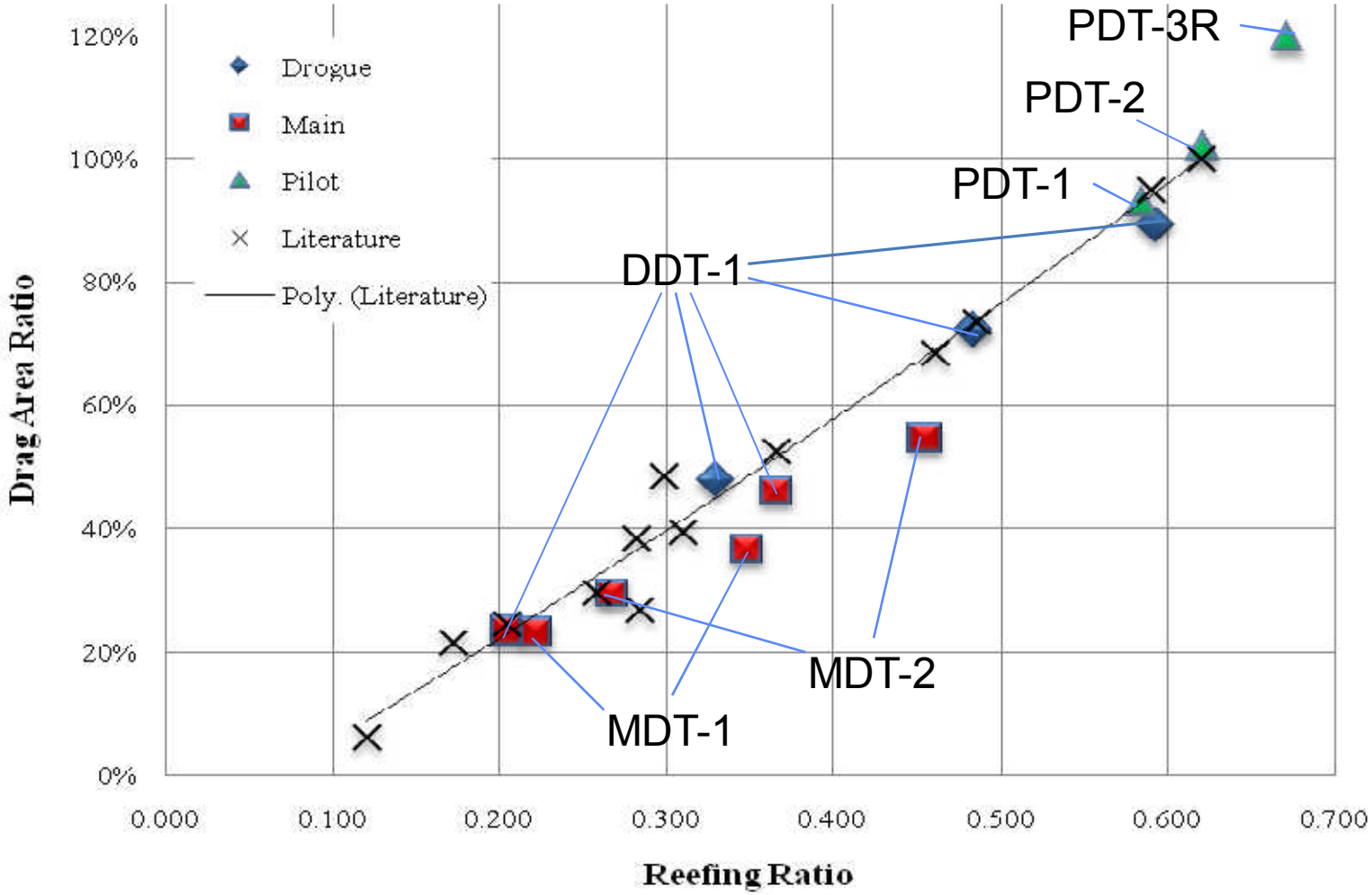
Effective Suspension Line Length

- Curves exist for determining the additional drag produced by longer suspension lines
- The Parachute Recovery Systems Design Manual (Knacke) provides a normalization
- Wolf and Croll provide a similar curve, but for ribbon parachutes of different porosities
- *These two curves disagree*
- When Ares I and SRB data are normalized with the Wolf curve, the reefing ratios match the drag areas predicted in the Parachute Recovery Systems Design Manual



Wolf and Croll, "Wind Tunnel Measurements of Dynamic Reefing Line Force in Ribbon Parachutes" J. Aircraft, Vol. 18, No. 1, 1981.

Ares I Drop Test Results – Normalized to $L_e/D = 1$



Conclusions

- Normalizing drop test reefed drag area for suspension line length with data from Wolf allows best match of test results with Knacke reefing ratio curve
- Various sizes and porosities of quarter spherical ribbon parachutes were tested
- All appear to fit the published reefing ratio curve – quarter spherical parachutes match

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